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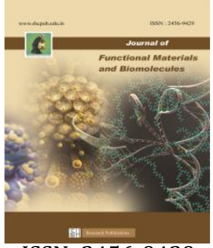

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Cyanobacteria – Based Biofertilizer for rice and aquatic cropping system

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Abstract

Cyanobacteria (blue-green algae) are among the earliest life forms and possess characteristics similar to both higher plants and gliding bacteria. Their ability to perform photosynthesis and nitrogen fixation enables them to thrive in diverse environments, including agricultural soils and rice fields. As natural nitrogen fixers, cyanobacteria contribute significantly to soil fertility and crop productivity. Biofertilizers such as cyanobacteria, *Rhizobium*, *Azotobacter*, *Azospirillum*, and *Azolla* provide cost-effective, eco-friendly, and self-sustaining alternatives to chemical fertilizers by enhancing nutrient availability and improving soil health. In addition, plant growth-promoting rhizobacteria and organic biostimulants support crop growth under both favorable and stressful conditions. Together, these biological inputs promote sustainable agriculture, improve soil vitality, and increase crop yields while reducing environmental impacts.

Keywords: Cyanobacteria, Microalgae, Soil fertility, Nitrogen fixation and Sustainable Agriculture.

1. Introduction

1.1 Cyanobacteria used as biofertilizer:

Since agriculture is essential to a nation's growth and survival, maintaining its quantity and quality is critical for both population feeding and economic exports. Many technical developments have been made in agriculture over the years to boost productivity. Because agriculture is essential to a nation's growth and survival, maintaining both its quantity and quality is essential for both population feeding and economic exports. Over the years, several scientific developments have improved agriculture's efficiency. Chemical pesticides and fertilizers have been crucial for increasing agricultural productivity since antiquity. Despite their short history in modern agriculture, they swiftly rose to prominence thanks to their cheap and quick reaction. Therefore, the emphasis on protecting eco-friendly plants has shifted due to their detrimental effects on the environment, plants, animals, and human life [1]. Anything from plant extract to manures is referred regarded as "biofertilizer". Biofertilizer, a bioactive component of specific microbial cells, accelerates the release of nutrients through several processes, including the phosphorus cycle and nitrogen fixation, which in turn promotes plant growth. The

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increased use of nitrogen-containing inorganic fertilizers in agriculture has resulted in decrease of soil quality, especially the depletion of beneficial bacteria in soil ecosystems. The usage of chemical fertilizers led to the improper management of soil nutrients. Because fertilizers are sprayed on the surface of the soil's available nutrients, which are largely recycled by microorganisms, yield grows greater under current agronomic practices. Consequently, biological fertilizers are being added to chemical fertilizers in agriculture. Biofertilizers, now known as bioinoculants, are low-cost, easily regulated, self-replicating, and ecologically safe inputs that increase and improve crop nutrient availability [1,2].

2. Algae-Based Biofertilizers

Recent years have seen an increase in microalgae biotechnological research on biofertilizers. Most of the newly published research use Chlorella sp. as the model mechanism. The ability of algae to endure in environments with exceptionally concentrated both inorganic and organic pollutants in different waste streams that are harmful to living things is their most remarkable potential. This is essential for enabling more efficient and sustainable agricultural production. Both autotrophic and heterotrophic microalgae are possible. Due to the success of sunlight conversion in some microalgae species, autotrophic evolution is currently the most widely used technique for producing this microorganism. The fundamental farming approach uses open ponds to create food supplements and antioxidants, and the productivity of these ponds varies widely based on the organisms and environmental conditions . Therefore, only certain hardy species such as the species Chlorella sp., Dunaliella spp., and Spirulina spp. that can tolerate harsh environments can grow microalgae in open systems. Closed-ponds, sometimes referred to as photobioreactors, can minimize growth area while offering defense against potential contamination [3]. This type of culturing procedure is used to manufacture several valuable molecules, including medicinal compounds. However, the main disadvantage of photobioreactors is their expensive initial and continuing operating costs. A viable approach is to generate algae under heterotrophic conditions using commercial bacterial-bioreactors that currently exist . This cultivation technology's main advantages are its high cell number, that may reach in excess of 100 g per liter; The highest density in photobioreactors is approximately 40g L^{-1}, whereas it is only 10 gL^{-1} in open-ponds. Utilising sewage from commercial, residential, and agricultural domains in bioreactors that enable the removal of impurities while generating microalgal biomass is one contemporary sustainable energy-based method for cultivating microalgae. Thus, by recycling products and materials and improving waste from various sources, including agricultural ones, microalgae can lessen their detrimental effects on the environment [4]

3. Soil Fertility

Although little is known about how it might impact soil nitrogen dynamics, the production of algal biomass from treatment of wastewater can enhance land usage as a biofertilizer. Studies on native Anabaena species have demonstrated that this strain can increase soil fertility without reducing soil density , even on terrain with reduced water availability and pesticide residues. Similarly, employing microalga Chlorella sp. cultivated in the liquid slurry, Marks et al. examined the impact of single-celled green algae on soil organic carbon [5]. According to their findings, soil respiration was greatly enhanced and Chlorella sp. grew photoautotrophically at a rate that was 3.5 times greater than that of plants grown in darkness and culture filtrates devoid of bacteria . The study of bacterial and algal consortia in the application of biofertilizer is another fascinating field of inquiry [6]. When compared to the usage of individual microbes, it may actually be more effective at detoxifying pollutants and removing nutrients from wastewaters. Additionally, these consortia may enable the soil to utilize its full supply of N, P, and K. Consortium engineering would be successful if bacteria and algae worked together to reduce pollution. Additionally, research indicates that consortiums of bacteria and algae have a lot of promise for improving marginal lands' soil and converting them into soil suitable for farming [6,7].

3.1 Nitrogen Fixation

One reason to use cyanobacteria as biofertilizers is their ability to fix nitrogen. The organic nitrogen produced by cyanobacteria from the inorganic nitrogen (N_2) in the air may be easily used by higher plants. In an effort to promote rice development, cyanobacteria have been used in Chile and India. Indigenous aquatic algae species in Chile have been shown to increase the nitrogen accumulation efficiency of rice paddles. The Azolla–Anabaena symbiotic N_2 fixing complex, which is made up of the free-living cyanobacteria Anabaena and the water fern Azolla, should be viewed as sustainable natural nitrogen resources in order to reduce inorganic nitrogen requirements, according to Vaishampayan et al. [7]. The cyanobacterium Tolypothrix sp was found. utilizes low-nitrogen water sources to produce bioproducts in tropical regions [7,8]. The soil-plant system retrieved more N_2 about cyanobacteria than from fertilizers that were synthetic when native colonies and N15-labeled fertilizer were compared [8]. This algae strain was highly successful in encouraging the establishment of the plant that produces rice due to its ability to fix nitrogen. In a different study, rice plants treated with immobilized plankton Chlorella pyrenoidosa utilizing dairy waste water overflow saw a 30% increase in root and shoot length.biofertilizer . In another study, Anabaena laxa and Rhizobium parasite and Anabaena combination inoculants were used to produce biofilm in chickpea growing. When the A. laxa virus was inoculated against the biofilm, grain yield rose by 50% (1,724 kilograms per hectare), compared to the control species (847 kg/ha). Furthermore, microbial association (21 different microorganisms, including antimicrobial antimicrobial bacteria, chlorophyta, etc.) was shown to have an excellent rate for nitrogen dioxide decomposition (10,294 nmol ethylene per gram dry weight/h) when used as a biofertilizer. The use of cyanobacteria as nutrient supplements in agriculture, especially for fixing of nitrogen in wet land production of rice, is explained in greater detail in a number of papers [8]

4.Formulation of Algal Biofertilizers

For commercialization, an algal natural fertilizer composition has been created and tested. Among these, Dubey and Verma employed clay-based inoculants to inoculate soil strains for extended periods of time. Even after four months, the amount of algae in the soil was roughly ten to seventy times more than that of the ignored plots [9]. After obtaining a soil-based starting culture, Mishra and Pabbi provided farmers with technology that enabled them to create the biofertilizer independently with the least amount of additional inputs. In order to increase the growth rate and output of rice plants, Tripathi et al. employed a technique known as "fly-ash," in which cyanobacteria as well as nitrogen fertilizer were combined. This strategy decreased the need for nitrogen fertilizers. The tests were compared with conventional soil-based cyanobacterial biofertilizer in the study that used cyanobacterial-based fertilizers that includes two messengers (wheat straw and multani mitti-clay) [10]. Both the soil-based and straw-based biofertilizer treatments demonstrated high yields when 90 and 120 kg N/ha were added, respectively. Thus, it was demonstrated that cyanobacterial biofertilizers may be developed to increase crop yield while lowering chemical fertilizer inputs in rice farming. Prasanna et al. and Renuka et al. also investigated the rice straw vermiculite and compost (1:1) as a carrier-based formulation. Wet blue green algae can be air dried or dried in an oven at 35 to 40 ° C for 24 hours in the dark to achieve cyanobacterial preservation [11]. Applying this technique to guarantee a high rate of germination is simple. Grzesik et al. found that foliar biofertilization by microalgae greatly increased productivity on willow monocultures. Studies have specifically shown that the creation of growth conditions and the application on the leaves of Acutodesmus dimorphus aqueous extracts have improved plant growth and seed germination. In Roma tomato plants, it was found that dimorphus cellular extracted and dry biomass could be applied as a biological stimulate and a biofertilizer to accelerate germination and improve plant growth and flower production [12]. The carrier-based formulation is better suited for N_2 fixing nutrients and soil conditioning, whereas the foliar-based formulation is better suited for germination-promoting effects, according to the aforementioned reports in the literature [13].

5.Cyanobacyerial in rice agriculture:

Often referred to as blue-green algae, cyanobacteria emerged extremely early in the evolutionary process and have a number of characteristics with both gliding bacteria and higher plants. Often referred to as blue-green algae, cyanobacteria originated very early with the dawn of life and share many characteristics with both gliding bacteria and higher plants due to their ability to both photosynthesise and fix nitrogen, along with their considerable level of soil type flexibility [14]. Cyanobacteria are widely distributed due to their capacity for both photosynthesis and nitrogen fixation, as well as their remarkable adaptation to many types of soil. Additionally, cyanobacteria have a special capacity to boost production in a range of ecological and agricultural contexts.. There have been reports of cyanobacteria growing both above and below the outermost layers in a variety of soil types. They are frequently also distinctive characteristics of various sub-aerial environments, including numerous sporadically moist ones like rice fields. The majority of paddy soils naturally contain cyanobacteria, which may be a free source of nitrogen fixation. Cyanobacteria can absorb ammonia as ammonium ($NH4^{+1}$) through a particular absorption method or by passive diffusion. There have also been reports of the amino acids glutamine, argenine, and asparagine acting as sources of nitrogen. Important sources include nitrate and nitrite., which eventually turn into ammonia. Nitrogen fixation is the term used to describe the ability of many cyanobacteria to use atmospheric nitrogen dioxide (N_2) as a source of nitrogen [15]. As in many other biological systems, nitrogen fixation in cyanobacteria is carried out by nitogenase, a highly organised, oxygen-labile metalloprotein enzyme. Nitrogenase transforms molecular nitrogen into ammonia when hydrogen is present.The usefulness of cyanobacteria in agriculture to increase productivity is undeniable because of this crucial aspect of nitrogen fixation. The use of dried cyanobacteria to inoculate soils to improve fertility has been the subject of numerous studies; the impact of cyanobacteria addition on rice yield was initially investigated.I was in Japan [16]. The use of a specific mixture of the cyanobacterial varieties to inoculate soil is now referred to as "algalization," and research on the process is ongoing in all of the main rice-producing nations. Grain yield has increased by 15–20% in field experiments, according to the average of these studies' findings. It has been proposed that if inoculation is carried out consecutively for three to four cropping seasons, the cyanobacteria introduced as a result of algalization can establish themselves permanently [17]. The fundamental process of mass manufacturing uses clean, sieved agricultural soil as a carrier material and a mixture of nitrogen-fixing cyanobacteria in shallow trays or polythene-lined pits filled with water kept outside.. Each pit is filled with water to a height of 12 to 15 cm, 10 kg of dirt, and 250 g of single super phosphate. Each multiplication unit is injected with starter culture, which is a blend of Anabaena, Nostoc, Aulosira, and Tolypothrix. To stop insects from reproducing, malathion (5–10 ml per tank) or carbofuran are (3% granules, 20 g per tank) are also added. After ten to twelve days of growth in the open sun, the cyanobacteria cover the surface in a thick mat during the hot summer months.After allowing the contents to dry, the dried shavings are gathered, packed, and applied to rice fields as an inoculant. The fundamental benefit of this technology is that farmers may make biofertilizer on their own with the least amount of extra inputs after obtaining the soil-based starter cultures [18]. Three to four days after transplantation, one hectare of crop fields can be inoculated with an inoculum of ten to twelve kilograms. Unfortunately, the farming community does not support the use of open-air algal biofertilizer production technology.The primary drawbacks of this technology include: 9 high levels of contamination resulting from outdoor production; 9 slow production rate; 9 a low density of inhabitants and consequently the need for overwhelming inoculum per hectare; and 9 the fact that it can only be produced for three to four months of the year (production must be halted during the rainy and winter seasons). In order for these organisms to be practically exploited on a wide scale, efforts have also been made to improve the technology by creating new, economically viable methods for producing high-quality inoculum. Only when multiplication is done in a controlled environment is this feasible. The discovery of new, inexpensive carrier materials that sustain greater cyanobacterial loads with longer shelf lives has significantly improved production technique, potentially lowering the amount for inoculum per unit area. The production of algal biomass indoors under controlled settings, a suitable and affordable growth medium for quicker organism growth, and combining with an appropriate carrier material are some of the fundamental advancements in technology [19]. Algae are grown indoors in a space that could be a glasshouse or polyhouse.The individual units in the polyhouses may be made of polythene-lined pits in the ground, brick and mortar, or RCC. To guarantee that every necessary strain is included in the finished product, the algae grows individually as species by inoculating different tanks with pure cultures grown in a lab. When the culture is fully developed, it is collected, combined with the carrier materials, presoaked using water and multani mitti (1:1) for an entire night, and then sun-dried. After being dried, the material is crushed, sealed, and kept in polythene bags of the appropriate size.One acre of rice producing land can be inoculated with 500 g of the end product, which includes ten thousand rupee to 10,000 units or propagules for every gram of carrier material [20]. Numerous field tests using this material have produced encouraging outcomes in terms of crop yield and nitrogen conservation [21]. However, statistical assessment of the observations on alagalization in fields of experiments has revealed inconsistent inoculation effects. Producing mixed inocula from local stocks and combining the biofertilizers with a small amount of nitrogenous fertiliser seem to yield the greatest results. fertiliser addition to rice.As long as the nitrogen content is low, cyanobacteria make up a significant portion of the flora. Green algae often take over the soil flora when high nitrogen fertiliser isapplied. Although deep urea implantation does not stop cyanobacteria from growing, surface fertiliser treatment usually inhibits their growth. The majority ofcyanobacteria that are inoculated in soil are unable to outcompete the native flora in the soil, and inoculated species can only take over in situations when the native flora is scarce. Thus, 'algalization' seems likely to be most useful where there are marked seasonal changes in land such as when ground is ploughed frequently before planting so that the natural soil inoculum is much reduced by the time of new paddy season [22]. 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Gaining a deeper comprehension of cyanobacterial population movements during the entire yearly cycle in agricultural systems is crucial. In-depth field research is also required to create a high-quality inoculum tailored to a certain area. In order to apply this strategy to dry crops, it may be helpful to comprehend the biology of drought-resistant cyanobacteria Pervasive [23] . Additionally, cyanobacteria have a special ability to increase productivity in a range of agriculturaland environmental circumstances. There have been reports of cyanobacteria growing both above and beneath the surface in a variety of soil types. They are frequently also distinctive characteristics of various sub-aerial environments, including numerous sporadically moist ones like rice fields. The majority of paddy soils naturally contain cyanobacteria, which may be a free source of nitrogen fixation. Cyanobacteria can absorb ammonia as ammonium ($NH4^{+1}$) through a particular absorption method or by passive diffusion [24,25]. The usefulness of cyano in agriculture to increase productivity is undeniable because of this crucial aspect of nitrogen fixation. The administration of drying bacterial to inoculate soils to promote fertility has been the subject of numerous research; the impact of cyanobacteria addition on yields of rice was first investigated in Japan in the 1950s. The use of a specific mixture for cyanobacterial varieties to inoculate soil is now referred to as "algalization," and research on the process is ongoing in all of the main rice-producing nations [26].

6.Phytohormones and Cyanobacterial Metabolites of Possible Agricultural Use.

Because of their biological activity, cyanobacteria and microalgae produce a wide range of metabolites that are capable of being used in agriculture as an biofertilizers, biostimulants, or biopesticides. Phenolic chemicals, terpenoids, FFAs, polysaccharides, carotenoids, and phytohormones are among these metabolites that are particularly interesting because they have previously been identified as promoters of plant development [27, 28]. The primary physiologically active cides are listed in Table 1. Phenolic chemicals, terpenoids, FFAs, polysaccharides, carotenoids, and phytohormones are among these metabolites that are particularly interesting since they have been identified as promoters of plant growth [29].

presents the main biologically-active compounds that can be extracted from microalgae and cyanobacteria for their benefits in agricultural practices

6.1 Phenolic Substances

Aromatic hydrocarbons joined to a hydroxyl group are known as phenolic compounds. These substances fall into two general categories: polyphenols and phenols. Subcategories of phenols include flavonoids, phenylpropanoids, and phenolic acids [30]. Many chemical, biological, and environmental factors affect the synthesis and release of phenols, which are considered secondary metabolites in microalgae. Phenolic compounds found in microalgae and cynobacteria are associated with their antioxidant properties [31], which are essential for their growth, reproduction, and defence against a variety of stressors [55]. Goiris and colleagues. assessed 32 microalgal populations' antioxidant activity and contrasted the findings with the total amounts of phenolic and carotenoids. The findings demonstrated that phenolic chemicals made a substantial contribution to the antioxidantproperties of the microalgae under study, second only to carotenoids. Tetraselmis suecica, Botryococcus braunii, Neochloris oleoabundans, Isochrysis sp., Chlorella vulgaris, and Phaeodactylum tricornutum were the microalgal species with the highest antioxidant capacities and phenolic contents (between 1.70 and 4.57 mg g−1 DW, dry weight basis). More recently, Foo et al. evaluated the relationship between the antioxidant capacity of six distinct forms of microalgae (five microalgae as well as one macroalga, respectively) and the amount of bioactive chemicals (such as carotenoids and phenolic acids, fucoxanthin), and fatty acid profile).Odontella sinensis & Skeletonema costatum exhibited moderate antioxidant efficacy, while P. tricornutum & Saccharina japonica had the smallest antioxidant activity. Chaetoceros calcitrans & Isochrysis galbana had the highest antioxidant activity. Using multiple linear regression analysis and Pearson correlation, the authors found that antioxidants (with values ranging from 0.05–6.13 mg g−1 DW) and phenolic acids (representing 0.02–12.24 mg g−1 DW) were the primary contributors to the antioxidant capacity of the studied algae. Because of their antibacterial, antifungal, and antioxidant qualities, phenolic chemicals primarily defend crops from infections and other stressors that are both abiotic and biotic [32].

6.2 Terpenoids

Terpenoids are chemical compounds that are produced when terpenes are combined with functional chains based on oxygen or methyl. Hemiterpenoids are made up of (one isometric unit of service, C5), monoterpenoids (five isoprene elements, C10), sesquiterpenoids (three isoprene units, C15), diterpenoids (four isoprene units, C20), triterpenoids, also known as (six isoprene units, C30), tetraterpenoids (eight isoprene components, C40), and polyterpenoids, which are (more than eight isoprene components, C33) >C40) [2,7]. Additionally, terpenoids fall into four primary categories: linear, rearranged, bicyclic, and monocyclic., depending on how many cyclic structures they include.These substances are secondary metabolism products of several cyanobacterial and algae species. The most abundant source of secondary metabolism products among algae is red algae (Rhodophyta), many of which are known to produce terpenoids. For instance, the genus Laurentia has yielded 512 sesquiterpenes as well as 133 diterpenes with various structures. Other red algae species that produce terpenoids include Chondrococcus hornemanni Hypnea pannosa Sphaerococcus, coronopifolius Plocamium cornutum Plocamium leptophyllum and Portieria hornemannii [28]. Genes producing digestive enzymes that are involved in the terpene biosynthesis pathway in cyanobacteria were discovered in Synechocystis sp., PCC 6714 and Thermosynechococcus elongatus. Major cyanobacteria that are known to produce isoprene include Prochlorococcus, Synechococcus, and Trichodesmium.

Finally, a few filamentous cyanobacteria, such as Pseudanabaena sp., Pseudanabaena articulate, Planktothricoids raciborskii, and Oscillatoria perornata, have also been connected to terpenoids [25]. Because of their bioactivity, especially in terms of their antibacterial, antioxidant, and anticancer activities, terpenoids are frequently used in pharmaceutical and cosmetic compositions.Terpenoids are being investigated as possible substitutes for fossil fuels since they are precursors of linear terpenes [25,57]. Terpenoids are useful resources for use as biopesticides in agriculture because of their antibacterial, allelochemical, and antioxidant qualities, which have a significant impact on crops defence against bacteria, insects, and other creatures [26]. Furthermore, terpenoids have been shown to have a significant impact on pollinator attraction and early plant growth and development [34].

6.3 Free Fatty Acids

Microalgal and cyanobacterial-containing crude extracts are common sources of FFAs, which are non-esterified fatty acids. FFAs are categorised as short, medium, long, and extremely long chain fatty acids based on the entire length of the chemical chain. Additionally, they can be separated into saturated (such as cis- and trans-fatty acids) and unsaturated (such as lignoceric, palmitic, capric, behenic, cerotic, caprylic, lauric, stearic, myristic, and arachidic acids) fatty acids [35]. Microalgal biomass from several species, including green, red, and blue-green algae, such as Anabaena, Chlorella, Dunaliella, Porphyridium, Scenedesmus, and Spirulina, was found to contain FFAs [29, 33]. Furthermore, cyanobacteria and microalgae have been shown in multiple studies to accumulate as much as The dry weight of 70 fatty acids. For example, in a research by Feller et al. [32], extracts of marine microalgae such as Porphyridium C. cruentum, N nochloropsis oculata, and P. tricornutum revealed 27.5 to 38.5% for polyunsaturated fatty acids, and 37.3–82.4% for saturated lipids. Due to the current need for renewable energy sources, FFAs from microalgae have been extensively studied as an alternative source for biodiesel manufacturing since they may be created through the evaporation of fatty acids [36]. In addition to its potential use as a renewable energy source, FFAs are recognised for their antiviral, antioxidant, anticarcinogenic, antibiotic, and antifungal qualities [37].

6.4 Phytohormones

Many plant cellular processes are regulated by phytohormones, which are thought of as signal molecules. Higher plants were among the initial to be discovered to possess these chemicals, which are typically synthesised in trace amounts. However, a wide range for microalgae as also produce similar signalling molecules, as demonstrated by the recent rise in algal research, especially microalgal genome studies. Indeed, the most commonly known phytohormones (auxins, abscisic acid cytokinins ethanol, & gibberellins), which have already been found in several algal lineages, including cyanobacteria, diatoms, brown, red, & green algae. These substancesAlthough there are still relatively few studies on biological reactions caused by microalgal phytohormones, the similarities between phytohormone concentrations in larger plants and algae suggest that their functions may be very similar. In higher plants, auxins, especially indole-3-acetic acid, are responsible for regulating growth and development. Because auxins that originate from C. vulgarise, D. salina Nannochloropsis Antarctica, Scenedesmus oblique, and Scenedesmus quadricauda have enhanced cell number, proteins and chlorophyll content, and cell division, these compounds also serve as growth regulators in microalgae.leading to increased biomass productivities Abscisic acid is often associated with how cells respond to environmental disturbances such drought, high salinity, and low nutrition levels. This substance often initiates cellular mechanisms that make plants more tolerant to different stresses and help them avoid their detrimental effects. It has been demonstrated that abscisic acid improves higher plants' resistance to temperature and salt stress by controlling ion and water absorption. In microalgae and cyanobacteria, this substance is very effective at controlling how cells react to salt, osmotic, oxidative, drought, and nutritional stresses. Carotenoids are often produced when the abscisic acid pathway is activated, and they often serve as oxidative stress defenders [62]. In higher plants, cytokinins mediate a number of functions, including cell division, development biogenesis, differentiation of chloroplasts, and control of seed dormancy [10]. Consequently, these hormones are essential to plant growth and development. In addition for these roles, cytokinins aid plants in surviving challenging environmental conditions [10,11]. Because they both encourage photosynthesis and cell proliferation while protecting cells from external stressors, these hormones have a very similar function in cyanobacteria and microalgae. Gibber amino acids form seedlings and microalgae/cyanobacteria have similar roles, primarily related to promoting development and causing the buildup of proteins and pigments [10,11]. Gibberellins from C. ellipsoidea, Chlorella pyrenoidosa, C. vulgaris, and the microorganism have been linked to quicker growth rates and larger numbers of cells in microalgae and cyanobacteria.[38]. Additional advantages of employing cyano and microalgae (as well as their extracts) in farming operations are highlighted by the regulating activities that these microorganisms (or their extracts) support, especially with regard for development stimulation and plant' defence from both biotic and abiotic impacts.

7. Cyanobacteria as functional foods

Proteins, carbs, vitamins, lipids, and minerals are among the essential nutritional components that functional meals offer in sufficient quantities . They might include bioactive compounds, which are naturally occurring substances that are beneficial to human health and come from plants, animals, or microorganisms. Cyanobacteria have nutritional, medicinal, and advantageous properties and could be utilized as food supplements. Cyanobacteria are an attractive alternative to sustainable food production due to a number of factors, including their widespread distribution, high nutrient content, low water requirements for development and advancement (saltwater can also be employed), ease of digestion, product constancy over a wide pH and temperature range, and the need for less land that may be unproductive and incompatible for other crops [20–22]. Cyanobacteria are currently sold as food supplements in a variety of formats, including liquids, tablets, and capsules [23, 24]. In addition to serving as a source of nutritious food coloring, they are thought to boost the nutritional content of foods for snacking, pasta, candy bars, gum, and drinks [25–30]. Due to its high protein content and important nutritional value, Spirulina (Arthrospria) has been the most commonly utilized cyanobacterial strain for human nutrition in recent years [27,31,32]. In terms of nutritional value, 1 kg of sprulina can replace 1000 kg of a variety of fruits and vegetables, according with particular statistical studies. In a number of nations, including Mexico, Chile, Peru, and the Philippines, certain cyanobacterial members such as Spirulina, Anabaena, and Nostoc are taken as dietary supplements. Aqueduct ponds or advanced photobioreactors are used to cultivate Spirulina platensis on a massive scale, which is then marketed as flakes, powder, pills, or capsules. More than 60% of it is made up of proteins, a wide range of preventative and therapeutic nutrients, minerals, trace elements, the antioxidant beta-car riboflavin, thiamine, and other B complex vitamins, and several unexpected bioactive substances [33–36].A number of businesses have started producing cyanobacteria on a significant scale as it became apparent that there was a need for extensive study on cyanobacteria-based functional foods. Culturing, harvesting, processing (drying), and packing are critical stages in large-scale production. Currently, goods with nutritional value derived from cyanobacteria are sold in over 70 countries [37]. Cyanobacteria are produced as functional food products by a number of commercial businesses. The need for cyanobacterial products to be produced on a large scale is growing, yet there are production-related restrictions that must be addressed.(. Therefore, in addition to maintaining and improving product quality, the development of effective technologies is required to lower production costs. Additionally, in order to gather the valuable germplasm, the selection of prospective cyanobacterial strains should be thorough and focused on study [40–42]. Additionally, limitations in respect to water constraints should be taken into account for potential alternatives such as seawater or wastewater [38]. Oscillatoria limnetica, Phormidium abronema, Oscillatoria tenuis, Lyngbya cryptovaginata, Tolypothrix tenuis [45], Spirulina platensis [46], Calothrix fusca and Gloeocapsa livida [47], Scytonema bohneri, Oscillatoria acuminate, Oscillatoria calcuttensis, Oscillatoria foreaui, Spirulina pacifica, and Spirulina platensis [48] are a good sources of proteins and carbohydrates.Spirulina's cholesterol-free lipids can help lower blood cholesterol levels and treat obesity, atherosclerosis, and diabetes [49–51]. Bacteria are the source of minerals and vitamins that are beneficial for bones, teeth, and blood; they contain the antioxidant vitamins A, B1, B2, B3, B6, E, H, folacin, pan tothenic acid, inositol, and a large amounts of vitamin B12 [49]. They also produce secondary metabolites that are the source of bioactive molecules like cytotoxic (41%), antimicrobials, antimycotics, herbicides, and other compounds (18%) [39].

8. Tolerance to Extreme Environmental Conditions

In terms of resistance to insecticides, Anabaena variabilis was found to be resistant to 100 μg/mL malathion by Ningthoujam et al. Jha et al. demonstrated that blue-green algae may be negatively impacted by magnesium ions and sodium (Na, -30.19%) in terms of saltiness tolerance; nonetheless, the negative interaction with Na permitted the algae to be utilised as an ameliorating material for salt-affected ground [39]. Another study found that the cyanobacterium Anabaena oryzae releases PO4-3 enzymatically under salt stress conditions, suggesting that it may be useful in alkaline (calcium (Ca^{2+})-rich) and high salinity soils. It is well known that cyanobacteria produce UV-absorbing compounds such scytonemin and mycosporine-like amino acids (MAAs) as a defence against constant sun exposure. These substances aid cyanobacteria in enduring challenging soil conditions.. The photoprotective defense techniques for cyanobacteria against deadly UV-B have been explored by Sinha and Höder [108]. These processes may be relevant to the use of cyanobacteria as biological fertilizers for agricultural crop growth. The adaptation of active microbes in the environment is the primary practical issue with commercialized biofertilizer [40].

9. Promotion of Plant Growth in Field Experiments

The diversity of species of soil microbes and plants is negatively impacted by long-term usage of nitrogen fertilisers, which also changes the content and structure of the soil [41]. In Andalusian paddy fields, synthetic nitrogen fertilisers are the main cause of cropland degradation as well as a decrease in soil microbe biomass along with ecosystem services [42]. Innovative fertilisation methods that incorporate prolonged sustainable farming methods are required to recover these areas. To promote nutrient cycling, repair deteriorated soil brought on by agricultural operations, and enhance plant health, biofertilizers containing soil-beneficial microbes have gained popularity. Applying cyanobacterial biofertilizers to rice paddies would be an environmentally beneficial strategy that advances sustainable agriculture. With the exception of the consortia inoculation, the three subplots that were handled as the main plot. Two inoculations were carried out: one month following planting, at the time of tiller initiation, and three months following planting, at the time of panicle mating. In the past, Asian nations including China, Vietnam, India, and others have employed cyanobacterial bioinoculants in place of nitrogen fertilizers for paddy agriculture. Numerous cyanobacterial species have been identified as effective biofertilizers, including Anabaena variabilis, Nostoc muscorum, Aulosira fertissima, and Tolypothrix tenuis [43]. To the best of our knowledge, this is the first use of autochthonous mycobacteria as biological fertiliser for the Andalusian crop fields, which are the major rice-growing region in Spain and among the most productive in Europe for the Indica variety. The model cyanobacterium Nostoc punctiforme has been shown to boost rice plant shoot/root length and weight in experimental settings [12]. The molecular mechanism of nitrogen fixed in heterocysts and plant phytohormones generated by cyanobacteria. This will be the subject of future investigation. There is little information available about commercial nutrient derivatives produced using cyanobacterial formulations.

10. cyanobacteria in sustainable agriculture

A worldwide concern is the careless application of pharmaceutical nitrogenous fertilizers in agriculture. There is an urgent need to find alternates to nitrogen fertilizers due to sustainability concerns. This option is provided by the biological fixation of nitrogen (BNF), a microbiological technique that transforms atmospheric nitrogen into a form that plants can use. A cost-effective and environmentally sound way to improve internal resources and decrease external inputs is through nitrogen-fixing systems [44]. Inorganic nitrogen fertilizers are extremely expensive to produce . Utilizing biofertilizer in a sustainable way helps crops that are deficient in nitrogen. PGPRs and EPS-producing cyanobacteria may help improve and restore soil sterility. Cyanobacteria play a major role in the biogeochemical cycles of the elements carbon, nitrogen, and oxygen. Their the present distribution in a variety of ecological niches is made possible by a number of structural and functional changes they have experienced throughout their existence. The ability of cyanobacteria to withstand a variety of conditions, including desiccation, high or low temperatures, salinity, and ultraviolet (UV) rays (UVR; 280–400 nm), gives them an advantage over competitors and neighbors in their natural habitats. Spirulina maxima, for instance, is known to thrive in environments with high salinity and alkalinity (pH 11), which provides it with an edge over competitors and grazers. Because of their ability to fix nitrogen, cyanobacteria can flourish in conditions when there is not much combined nitrogen. This feature makes cyanobacteria useful as biofertilizers from an agronomic and economic standpoint. Several cyanobacteria have the capacity to establish symbiotic partnerships, which could be utilised to construct microorganism associations to assist in the ecological remediation of affected aquatic systems or soils. Native cyanobacteria strain that have become accustomed to the local climate can thrive in wet soils. This significantly affects the nutritional status, agricultural output, and structural integrity of the soils. Twenty-five percent of cyanobacteria are composed of exopolysaccharides (EPS). EPS holds soil particles together, while cyanobacterial activity takes place in the upper crust of the soil.The EPS has the ability to bind soil particles together, It encourages soil aggregation, the accumulation of nutrients, and an improvement in the soil's top layer's capacity to hold water. This increase in the soil's moisture and organic content may allow plant-growth promoting rhizobacteria, also called PGPR, to thrive and multiply.may allow plant-growth promoting rhizobacteria, or PGPR, to thrive and multiply.. Therefore, cyanobacterial growth improves the chemical and physical characteristics of soils, and PGPRs and EPS-producing cyanobacteria may help to restore and enhance infertile soils [45].

11.Cyanobacteria use as a biofertilizer

Because inorganic nitrogen fertilizers require a significant amount of energy from fossil fuels, their production is quite costly. This made it necessary to create alternative, economical, and sustainable biologically accessible nitrogen sources that might sustainably meet agriculture's nitrogen needs . Biological systems that can repair atmospheric dinitrogen have been found for this purpose . Every year, Mt of nitrogen is contributed by biological nitrogen fixing . Metting states that 100% nitrogen fixation is possible. Symbiotic and free-living eubacteria, including cyanobacteria, are two groups of nitrogen fixing organisms. The free-living cyanobacteria fix the cyanobacteria based biofertilizers are cost-effective as they cost one third to that of chemical fertilizers .Apart from fixing nitrogen, cyanobacteria also help mobilize inorganic phosphates by excreting organic acids needed and extracellular phosphatases. Cyanobacteria increase the crop's access to phosphorus by solubilizing and mobilizing the insoluble organic phosphates. Strong reducing conditions are created in the soil by the humus content produced after cyanobacteria die and decay, improving the soil's fertility and structure. Since many cyanobacterial strains are known to produce siderophores and plant growth hormones, cyanobacteria can have an impact on crop development and yield. By increasing the build-up of organic matter and water, the exo-polysaccharides released by cyanobacteria cause soil particles to aggregate, improving soil fertility and structure. Together, these results demonstrate the value use bacteria are biofertilizers, and techniques for their production and application in the fertilizer sector have been devised [46]. Generally speaking, biofertilizers are organic substances derived from live microorganisms that provide vital nutrients like nitrogen, phosphate, potassium, and other inorganic nutrients to support the growth of seeds, plants, or soil bacterial consortia. They should be differentiated from NPK fertilizers, which are based on potassium (K), phosphorus (P), and nitrogen (N), the three primary nutrients required in large amounts for the healthy growth of higher plants Nitrogen-fixators, phosphate and potassium-solubilizing biofertilizers, phosphorus-mobilizing biofertilizers and biofertilizers for secondary macronutrients, zinc iron solubilizers, plant-growth-promoting rhizobacteria (PGPR), and compost are among the microorganisms that are used to classify biofertilizers and the benefits they provide. Biofertilizers will offer renewable and environmentally friendly solutions for modern agriculture, particularly in the form of integrated nutrient management (INM) and integrated plant nutrition system (IPNS), which may lead to sustainable economic development. These remarkable features include increased soil fertility, decreased energy consumption and contamination of soil and water, improved crop productivitper area in a relatively short time, and promoted antagonism and biological control of phyton-pathogenic organisms. However, biofertilizers have a number of drawbacks, including a limited shelf life (3–4 months) and storage requirements (low temperatures due to temperature sensitivity). According to recent research, several photosynthetic microorganisms, including cyanobacteria and microalgae, can be employed as soil conditioners and biofertilizers . Chlorophyta (green algae), Rhodophyta (red algae), Phaeophyta (brown algae), Euglenophyta, Pyrrophyta, and Chrysophyta are the general divisions of microalgae The only photosynthetic prokaryotes that can produce oxygen are cyanobacteria. There are about thirty thousand different species of both unicellular micro algae and more complex multicellular organisms; of these, 150 genera and over 2000 species of microalgae have been identified. Since the first decade of the , when productivity and yields were first investigated in mass culture , research on manufacturing processes of algae has been carried out. The primary advantages of algae are their capacity to grow on otherwise unproductive landSince algae may be grown under stormwater along with water from agriculture, recovering extra nutrients and reclaiming groundwater for future use, they are widely thought to have a significant impact on vital ecosystem services. By absorbing atmospheric carbon dioxide and nitrous oxides from industrial sources, they can also lower greenhouse gas emissions. The most basic live autotrophic microbes are thought to be cyanobacteria. These organisms are found throughout the aquatic environment and have the ability to construct food from inorganic substances . Cyanobacteria are an efficient source of biofertilizer to enhance the physicochemical properties of soil because of a number of special characteristics, including their capacity to hold water, short generation time, ability to fix atmospheric N_2, and adaptability to harsh environments .An overview of the primary techniques for extracting microalgae, their bioactive chemicals, and their agricultural applications is provided in this work. Additionally described are biostimulation mechanisms that affect the plant microbiome, anatomy, resilience to abiotic stress, and plant performance. Perspectives for additional investigations on microalgaebased biostimulants are presented, taking into account the state-of-the-art. These include developing crop-tailored, highly effective products and using them to increase agricultural sustainability [47]. Through exudation or microbial decomposition following cell death, cyanobacteria mostly release fixed nitrogen at the manner of polypeptides, with a smaller quantity of amino acids that are free, vitamins, and auxin-like compounds. A portion half the nitrogen that is fixed is transformed into available to rice plants in field settings, while the remainder is reabsorbed into the soil. Using the ~SN tracer technique, the spread of It has been studied how cyanobacteria provide fixed nitrogen to crops and other creatures. Rice from 15N-labeled Aulosira species was found to have 37% and 51% of the nitrogen. Both active absorption and passive processes that are distributed across the soil and are incorporated throughout the soil itself, respectively, could result in the uptake. found that at maturity, 40% of the static N in the rice part was not directly exposing ~SN2. However, the rice plants used the 15N/14N tracer approach to retrieve 40% of the eyanobacterial nitrogen.It has been demonstrated that resolved nitrogen from cyanobacteria has been directly transferred to rice plants; additionally, the incorporating ammonium chloride equivalent to 100 kg N ha -~ had no negative effect on the recovery of cyanobacterial nitrogen. Release of dissolved organic nitrogen 50% of N_2 fixation using comparable methods The amount that was available of tsN from cyanobacteria absorbed toward the environment ranged from twenty-three percent to twenty-eight percent during the first crop and from 27% to 36% of the second, according to research on marine cyanobacterium. In pot tests, these authors further showed that cyanobacterial ~SN was less accessible for the first crop than $(NH_4)2SO_4$, but that its availability was fairly similar for the second crop. Following two harvests, 30–40% of $(NH_4)2SO_4$ and 57% of 15N from cyanobaeteria persisted in the soil, indicating the cumulative effect of cyanobacterial inoculation and the slow-release characteristic of cyanobacterial nitrogen. The disparity between the readings indicates that the cyanobacterial material's susceptibility to decomposition, which changes not simply with the kind of bacteria however additionally with the physiological circumstance, determines the level of accessibility from cyanobacterial nitrogen to rice. A marine cyanobacterium has been found to emit dissolved organic nitrogen fifty percent (50 percent of N_2 fixation) using comparable SN tracer methods [48].

13.Cyanobacterial Influence on Soil Properties and Roots

Cyanobacteria release growth-stimulating compounds such as cytokinins. Rice seeds pre-soaked in extracts from cyanobacterial cultures demonstrated improved germination, encouraged root and shoot growth, and increased grain weight and protein content. These effects, which were additionally identified from many other creators, have been linked towards growth-modulating components; for example, hormones and vitamins Nevertheless, a cyanobacterial enhancer still needs to be found and explained. At the germination and growth office, Pedurand and Reynaud screened nonaxenic cyanobacterial isolates and found that 30% of the impacts had no effect on germination, while 30% caused inhibition, and 8 types of Anabaena stimulated growth of which only one remained effective after becoming axenic. This suggests that only the positive results in this area were probably considered for reporting. Further critical research on cyanobacteria's potential to form hormones and vitamins is required because they have been demonstrated to improve soil organic satisfaction, water-holding capacity, N enrichment, and the formation of additional polysaccharides that improve soil aggregation and phosphate solubilisation.Whether or whether the columns were purposefully inoculated, the cyanobacterial counts in this experiment eventually reached 104 g-t dry soil. Significant improvements were observed in the features of soil aggregation as well as a rise in the activities of phosphatase, urease, and dehydrogenase. These three enzymes' activities were smaller than in arable soils, indicating that these enzyme activities may be somewhat limited by wet conditions. The rice-grain-yield measurements indicate that this type of application yields both cumulative and residual effects, as evidenced by the accumulation in both organic compounds and the total quantity of cyanobacterial propagators in the substrate, thus which encourages the restoration of the cyanobacterial biomass. Several reports show that rises through organic material and nitrogen amounts in soils contaminated using cyanobacteria in pot and field conditions indicated the possible role of cyanobacteria in relation :However, the extracellular polysaccharides that cyanobacteria release improve the features of soil aggregation. This is significant because the organization and aggregation of soil aggregates impact the soil's temperature, aeration, and infiltration rates, all of which enhance the crop's physical environment. The effects from Nostoc strain on two clay soils from Tuscany were investigated in order to demonstrate both the initiation of aggregation and the protection of soil porosity through the mitigation of the detrimental effects of water addition. Phosphate fertilisers were observed to boost the amount of N added by cyanobacteria inoculation, and both total and organic N levels suffered past the tilling stage.Kleiner and Harper's findings, which showed that layers with cyanobacterial cover had more extractable P than neighbouring soils without cover, demonstrate the cyanobacterial capacity to mobilise insoluble forms of inorganic phosphate. Tricalcium phosphate was solubilised by 17 of the 18 strains examined. The ability of 50 cyanobacterial strains, excluding some soil isolates, to grow with organic phosphates as their only P source was assessed. It was discovered that all strains used the monoesters, nearly all used the diesters, and only a small number used phytic acid. The cyanobacterial P-solubilizing activity also acts on hydroxyapatite and Musso-rie rock phosphate.The majority of these strains did not release phosphodiesterase, but they did release a portion of their phosphomonoesterase extracellularly. There is some data on the efficiency of cyanobacteria in increasing P availability in salty soils, however further scientific interpretation is required. Cyanobacterial inoculation caused a slow rise in organic carbon in a long-term experiment, but after three years, the amount remained constant. Additionally, according to Bisoyi, cyanobacterial inoculation had no discernible effect on soil characteristics during the first and second rice-cropping seasons. However, in the third season, cyanobacterial inoculation produced 2–11% increases in soil organic carbon.It has been observed that cyanobacterial growth causes the pH of the soil to rise initially before falling back to its previous level. Additionally, it was demonstrated in these experiments that P content dropped during the first Ninety days of microorganism growth before starting to rise in the latter stages of incubation. Cyanobacterial inoculation combined with gypsum had a notable reclamation property that applied to sadie soils, according to Subhashini and Kaushik. They also observed a significant increase in the total N content of the soil concurrent with cyanobacterial growth, as well as a significant decrease in pH, electrical conductivity, exchangeable sodium, hydrolic conductivity, and gathering status of the soil.When Anabaena torulosa was cultivated repeatedly, the salinity of a soil that had become saline due to inadequate farm management was reduced by 25–30%. After cyanobacteria from salinity rice fields were investigated, a halotolerant bacterium known as Anabaena sp. was shown to be an efficient nitrogen fixer. According to reports, cyanobaeterial improvement in flood-damaged rice fields influences the forms of Zn in the soil. The ammonium acetate-extractable forms of Fe and Mn decreased as a result of their presence, but other forms of these elements increased.These alterations were thought to be caused by the insertion of organic matter, particularly extracellular material, and the release of oxygen. The breakdown of the cyanobacterial substance caused additional alterations in the different fractions, which were attributed to the creation of organic acids and the establishment of reducing conditions. Zn deficit in rice may be reduced by a lower concentration of easily accessible FeIt was also thought that other animals' access to the elements was impacted by the sheath. These authors examined whether Festuca organisms growing on soils heavily loaded alongside cyanobacteria/cyanolichens had significantly greater concentrations of N, P, K, calcium, magnesium, magnesium, calcium, and Fe compared to plants using the same medium where the crust had been eliminated. Mentzelia multiflora had far higher quantities of N, Mg, and Fe but much lower concentrations of P. The near-surface root layer's direct competition with the surface crust may have led to the reduced P absorption, while microbe-mediated stabilisation of N_2 is actually expected to increase the amount of N available to surrounding plants [49].

14. limitation of cyanobacteria

In addition to producing useful secondary metabolites, cyanobacteria also create poisonous substances or metabolite that are detrimental to both the environment and living things. Cyanotoxins include peptides, which cyclic amine alkaline compounds, and non-protein amino acids. The literature indicates that non-terrestrial environments contain the most studied cyanotoxins. Numerous factors, many of which have unknown, affect the quantity of cyanotoxins emitted. The proportion of toxic to benign variation in genes, or the kind of toxins that have been either free or bound to exposure to toxins can occur directly or indirectly. Food products that are indirectly polluted with cyanobacteria or bioaccumulated cyanotoxinsof drinking and other sources happens in the direct path.Cyanotoxin poisoning of water bodies initiates an unregulated loop that contaminates nearby plant systems and soil. As a result, poisons are transferred through drinking water to soil and ultimately to people and animals. Furthermore, the primary source of cyanotoxins in the soil is thought to be the use of tainted water for irrigation. The soil absorbs the water, increasing the likelihood that it may seep into the groundwater. It can spread from groundwater to nearby bodies of water. In a similar manner, the plant roots absorb the cyanotoxins that from the toxin-rich irrigation water.These poisons begin to build up in the plants' fruits and leaves, endangering living things. Cyanotoxins change the structure and functions of microorganisms. In a similar vein, it influences many microbial activities including nitrification. Additionally, it has been claimed that biocrust has a specific amount of cyanotoxins. In addition to using contaminated water for irrigation, direct application of toxic cyanobacteria biomass as biofertilizers also contaminates soil. Due to difficulties with effective extraction methods and cyanotoxin quantification, soil cyanotoxins have not been thoroughly investigated. Choosing an appropriate extraction solvent that will effectively collect and separate toxic substances from the soil aggregates is the most difficult phase in the extraction of cyanotoxins from soil. Because of their rather solid structure, cyanotoxins are difficult for the environment to break down. Cyanotoxins are eliminated from soil by a variety of mechanisms, including microbial and UV destruction. Although light-assisted UV degradation has been thoroughly investigated, its exact nature in soil remains unknown. Additionally, it is suggested that cyanotoxin is adsorbed on soil particles.. Because it can change both the cyanotoxins' surface charges and the total electrical charge of the ground's particles, the acidic pH of the soil itself also has an impact on the cyanotoxin's binding affinity with the soil. According to research, soil's chemical makeup also contributes to the removal of pollutants. For instance, it has been found that soil with high amounts of organic C (2.9%) and clay content (16.1%) is better at removing cyanotoxins than other soil types. This is a problem for dry areas with a higher proportion of sandy soil. The idea that small particles was unable to be eliminated from sandy dirt with a 98% sand content was supported by another study. The study also verified the importance of clay in removing contaminants from the soil.The attraction of pathogens onto the metallic ions in the soil facilitates the breakdown of microcystins. In this manner, microcystins can persist for prolonged periods of time if they are not eliminated. Furthermore, it is said to be important in the breakdown of cyanotoxins, including microcystins. Only 14% of the sum of all microcystins in the soil are adsorbed on the soil's surface; the remainder microcystins are thought to be broken down by the soil's bacteria.Similarly, a more significant restriction is that PCR or qPCR may not be able to identify toxic species with distinct gene sequences. Finally, toxicity determinants based on cells and enzymes are less accurate and precise due to possible interfering variables. It is crucial to conduct additional research on detecting methods and develop a dependable and effective strategy, taking into account the benefits and drawbacks of each technique. One method may be most effective for one class of cyanotoxins, but it may not be effective for another [50].

Conclusion.

Cyanobacteria provide a cost-effective and environmentally sound substitute for chemical fertilisers. Nitrogen fixation by free-living cyanobacteria also greatly increases soil nitrogen in a wetland rice habitat. The growth of green agriculture has benefited greatly from algae-based biofertilizers. shows potential study topics for high energy generation combined with algae-based biofertilizers. In addition to fixing N_2, they can improve fertility in the soil and give crops the PGPR benefit. Certain algal fertilisers are renewable resources for sustainable agriculture since they can be generated as metabolic byproducts during wastewater treatment procedures. Chemical fertilisers used in modern agricultural techniques have decreased soil fertility, rendering it unsuitable for growing crops. Severe dangers to health and the environment such as erosion of soil, contamination of waterways, pesticide poisoning, declining ground water tables, water logging, and biodiversity loss have also resulted from the overuse of these inputs. Biofertilizers are becoming increasingly important for use in crop production because they spontaneously activate the microorganisms present in the soil in an efficient and environmentally friendly manner, replenishing the soil's fertility and shielding it from drought and soil diseases while also promoting plant development.

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